

Satellite and Airborne Remote Sensing Investigations

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The objective of this study was to evaluate data acquired by the spaceborne high-resolution EO-1 Hyperion and Advanced Land Imager (ALI) sensors by integrating it with hyperspectral data from airborne sensors. This data was applied to three investigations: (1) urban and industrial mapping in Venice and Porto Marghera, Italy; (2) bathymetry using a site in Lake Tahoe, California; and (3) wetlands vegetation in the Venice Lagoon. As well as using the sensors aboard EO-1, these investigations used data acquired by TERRA ASTER, the Landsat 7 Enhanced Thematic Mapper Plus (ETM+), the Multispectral Infrared Visible Imaging Spectrometer (MIVIS) airborne imaging spectrometer, and IKONOS.

Venice Urban Mapping:

Venice consists of a low-lying land mass intersected by a number of canals. It is situated in a lagoon and also borders the ocean. Several islands near the largest land mass also are considered part of the urban area. In total, this study area encompasses a dense urban environment, a polluted lagoon, and the offshore waters of the Adriatic Sea.

Data from all six sensors were used for the urban mapping investigation. Figure 1 shows Landsat ETM+, MIVIS, and EO-1 ALI and Hyperion images for a similar area, acquired from March through July 2001. Figure 2 shows representative images for the area under study at the spatial resolution of each of the above sensors as well as for ASTER and IKONOS and provides the number of available bands.

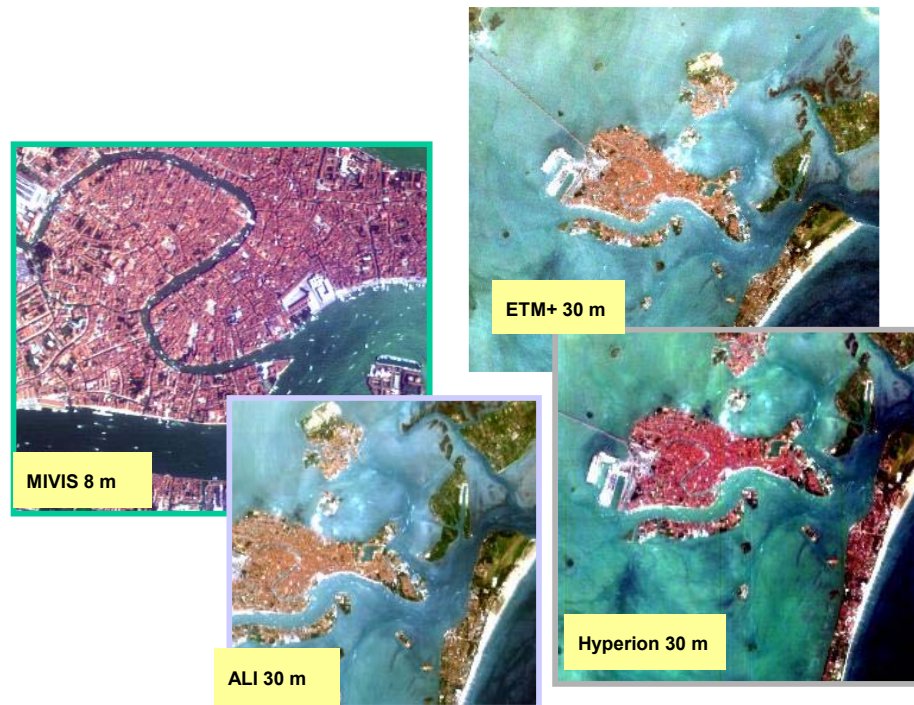


Figure 1. Similar images acquired from MIVIS, ALI, ETM+, and Hyperion.

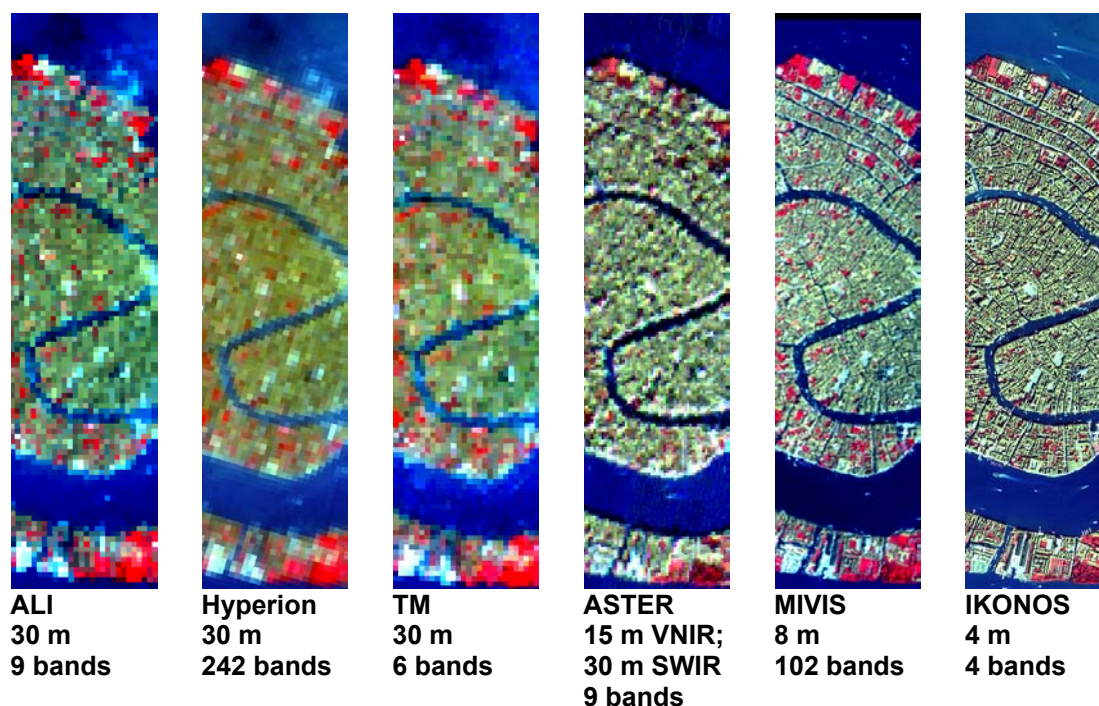


Figure 2. Spatial resolution and number of bands for each sensor.

A total of six study sites were used. The Malamocco Golf Club on the island of Lido was used to inter-calibrate the instruments used in the study by means of a group of balloon-borne instruments. The industrial area of Porto Marghera, an area equipped with several meteorological stations, also provided measurements for calibration purposes. The Marco Polo International Airport provided easily identifiable features such as runways and parking lots that were helpful during the data calibration phase. Another area was a crop area a short distance north of the airport characterized primarily by cultivated fields and very small groves of trees. Also, the Acqua Alta ocean platform in the Adriatic Sea was equipped with a cluster of permanent instruments for measuring wind, direct solar radiation, the tide, and sea waves. An additional land site was located at Pellestrina to the south of the golf club.

Data acquired by the different sensors was subject to various pre-processing (Table 1). In addition, a variety of image processing techniques was applied to the data, including using the pixel purity index (PPI), mixture tuned matched filter (MTMF), minimum noise fraction (MNF), and spectral angle mapper (SAM) techniques.

Table 1. Venice data pre-processing.

	IKONOS	MIVIS	ASTER	ALI	Hyperion	ETM+
Adjustment of VNIR and SWIR geometry					X	
Conversion to radiance at sensor		X	X	X	X	X
ACORN atmospheric correction		X Modtran	X	X	X	
Registration to IKONOS with NN		X GPX/INS	X	X	X	X

In a validation area, each of the instruments successfully differentiated a number of materials. The level of each material was given as a percentage of the total number of pixels observed in an

area. The number of pixels varied among each instrument although the relative number of pixels was consistent in most cases. Table 2 shows the percent of pixels that were identified as vegetation, tile roof, or pavement for each of the sensors.

Table 2. Percent of pixels identified in three classes.

	Vegetation	Tile Roof	Pavement
ALI	6.1	10.6	2.3
ETM+	3.7	13.3	2.3
Hyperion	3.0	12.8	9.5
ASTER	5.1	8.0	14.6
MIVIS	4.7	6.7	7.5
IKONOS	2.9	7.3	4.3

As mentioned above, various processing techniques were applied to sensor data. For a MIVIS scene, the entire roof dataset was spectrally investigated using a PPI procedure. Two different spectra were recognized as corresponding to brick coverings of new and old buildings. The spatial recognition of such covering materials was obtained by means of a SAM classification procedure. This procedure also stressed the orthogonality of the two selected spectral classes (new and old tiles—Figure 3).

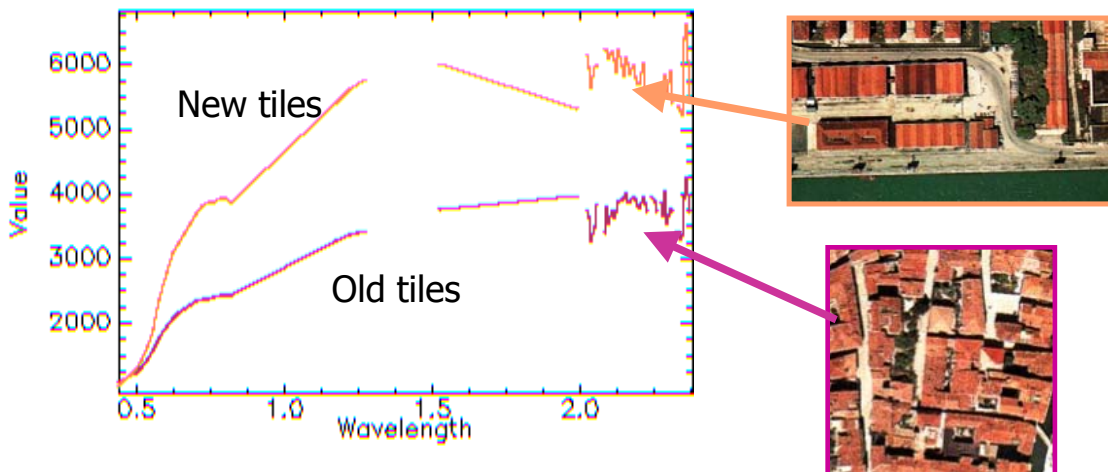


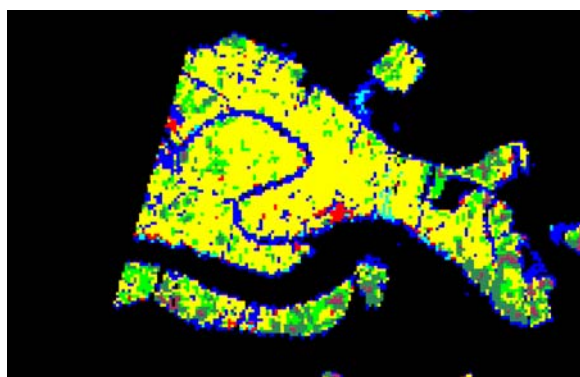
Figure 3. Mapping of old and new tiles using MIVIS.

Metallic coverings, asphalt, and trachyte spectral classes were classified using a MTMF procedure to derive the abundance of each input spectral class (Figure 4). (Trachyte is a type of igneous rock.)

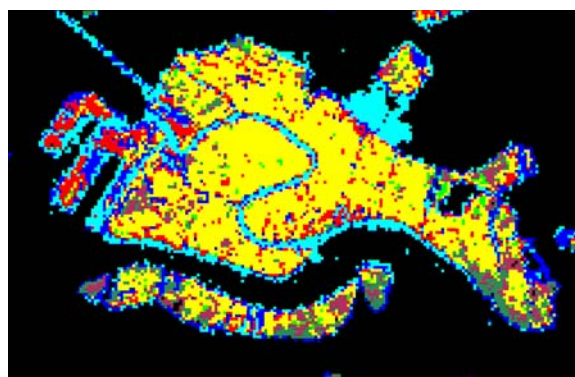


Figure 4. MIVIS Mapping of metallic roofing, trachyte, and asphalt with 8-m pixels, 102 bands.

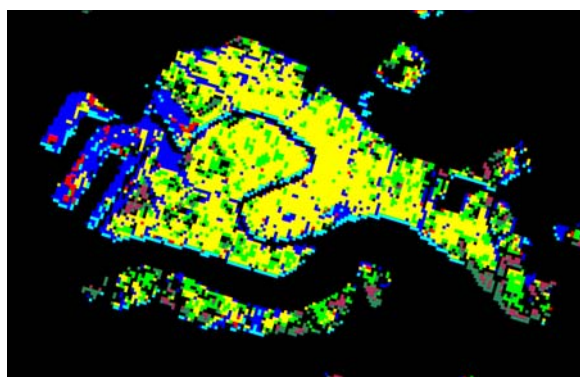
Figure 5 shows mapping of the same area using the SAM image processing technique for each of the sensors.



ALI



ETM+



Hyperion



IKONOS

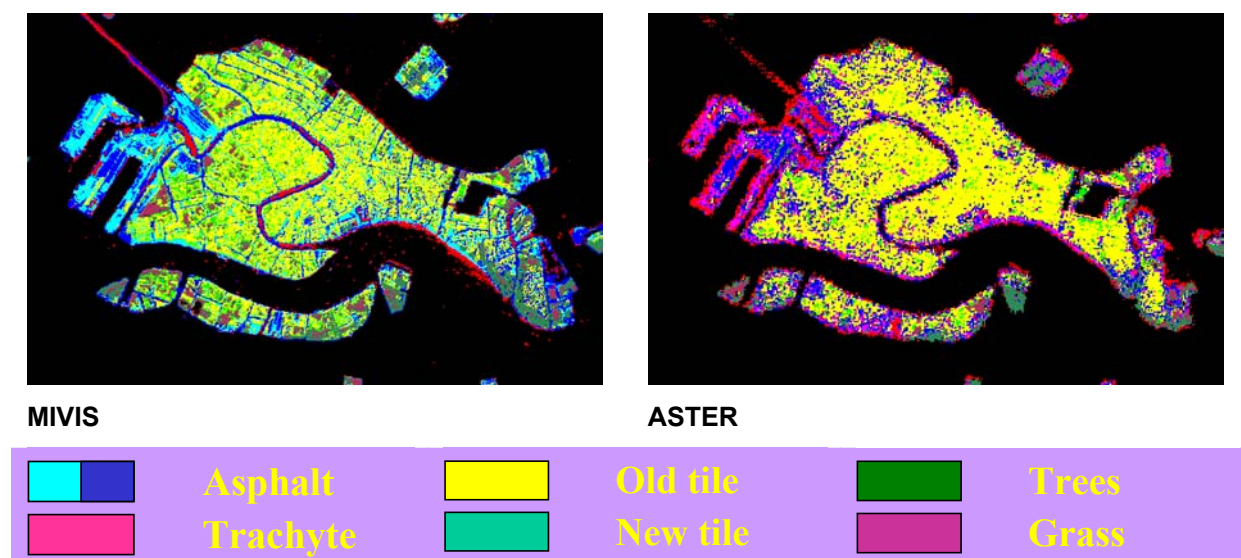


Figure 5. Spectral Angle Mapper classifications.

Hyperion data were unmixed by using end-members derived from MIVIS data. Both MIVIS and Hyperion data were converted to radiance at the sensor. Atmospheric correction was applied, and Hyperion resampled to the MIVIS spectral bands. Datasets were co-registered, and the empirical line method used to normalize Hyperion to MIVIS, using MIVIS image spectra.

Conclusion

Overall, the ALI, ETM+, and Hyperion datasets, all at 30 meters resolution, provided generally similar results. ALI allowed better mapping than ETM+ because of its larger number of bands and higher signal-to-noise ratio. Hyperion mapping was similar to that of ETM+ because of its low signal-to-noise ratio, even though its larger number of spectral bands should improve mapping. ASTER 15-meter data was better than any of the 30-meter data, due to the smaller pixel size. MIVIS data, with its 8-meter pixels, were better yet because of its hyperspectral coverage and high spatial resolution. IKONOS data provided the greatest detail, the least amount of mixed pixels, and could separate all of the urban classes.

Bathymetric Analyses at Lake Tahoe:

In this investigation, researchers obtained simultaneous ALI, ETM+, and ASTER datasets for an area of Lake Tahoe, California, to examine the abilities of the three sensors to penetrate its waters and see the bottom (Figure 6). Lake Tahoe is an attractive test site because of the exceptional clarity of its water (60+ feet), thin atmosphere, and infrequent cloud cover; however, visibility into its depths has declined from approximately 120 feet to 70 feet during the last 35 years. Depth vs. radiance profiles were extracted for the study area using ALI, ASTER, and ETM+ data. Data for this study was acquired on September 1, 2002.

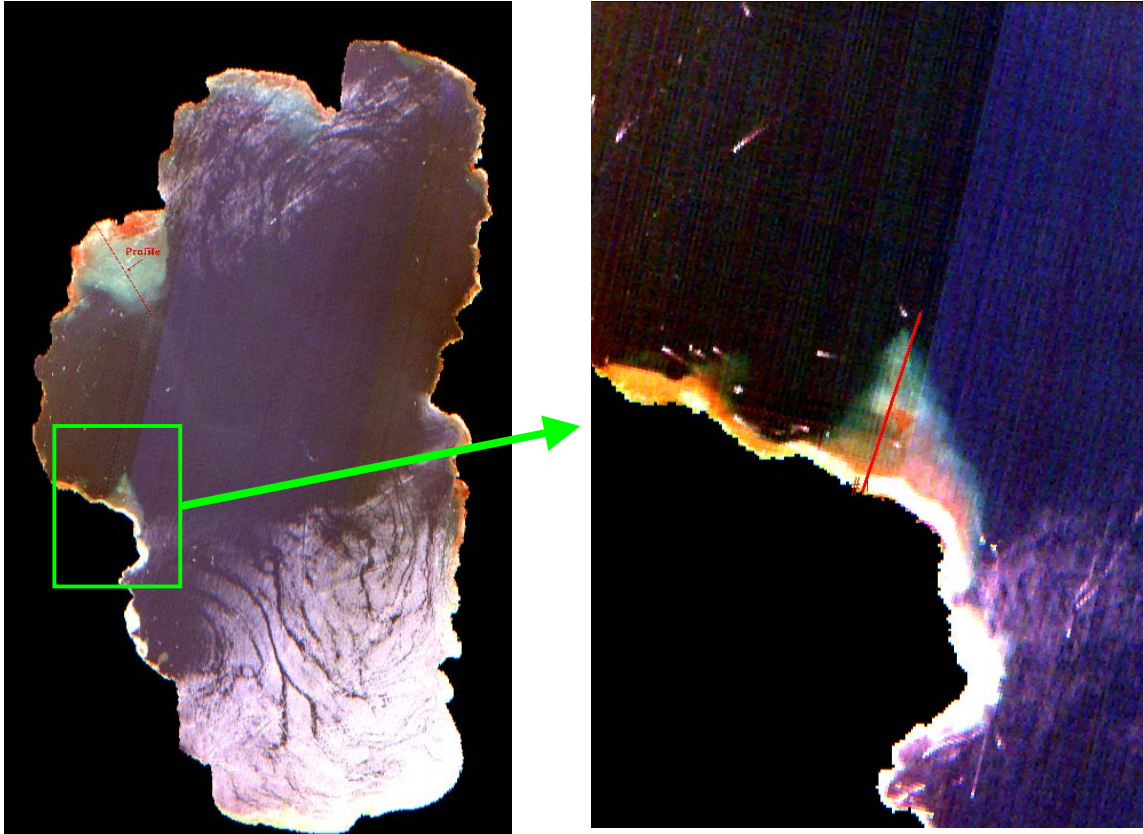


Figure 6. (Left) ALI Bands 2, 1', and 1 in red-green-blue for Lake Tahoe. The land area in the investigation is boxed off. (Right) Sub-area used to produce profiles of depth vs. radiance for ALI, ASTER, and ETM+ data.

ALI has two characteristics that potentially improve water penetration in clear waters when compared to Landsat ETM+: it has higher signal-to-noise and it has an additional band--a far blue band at a shorter wavelengths than ETM+ Band 1.

Plots were created for ALI Band 2, ETM+ Band 2, and ASTER Band 1 (Figure 7). All three instruments have similar bandpasses of 0.52-0.60 microns. ALI and ETM+ are at 30-m pixel resolution, and ASTER is at 15-m resolution (resampled to 30 meters for this analysis). All three data sets were converted to radiance using provided calibration coefficients.

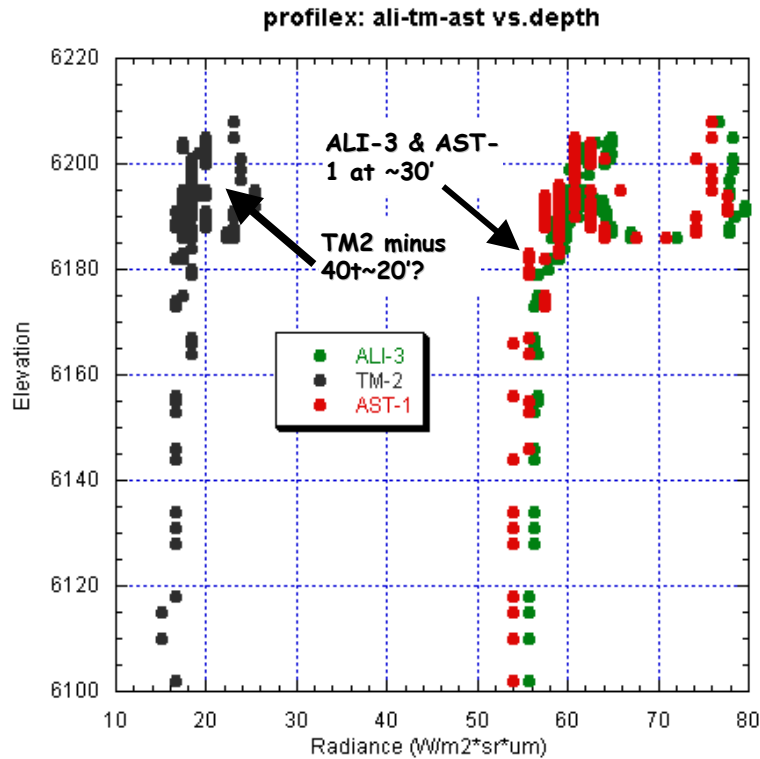


Figure 7. Depth vs. radiance plots for a profile from the shore of Lake Tahoe. The three similar 0.52-0.60 micron bands for ALI, ETM+, and ASTER were plotted. Elevation refers to number of feet the lake is located above sea level.

Data from both ALI and ASTER suggested that the bottom could be seen to a depth of 30 feet. ETM+ data were noisier, and might allow 20 feet of penetration before the radiance values became uniform. One saw a similar effect when looking at the same area with ETM+ Band 1 and the equivalent ALI band (Figure 8).

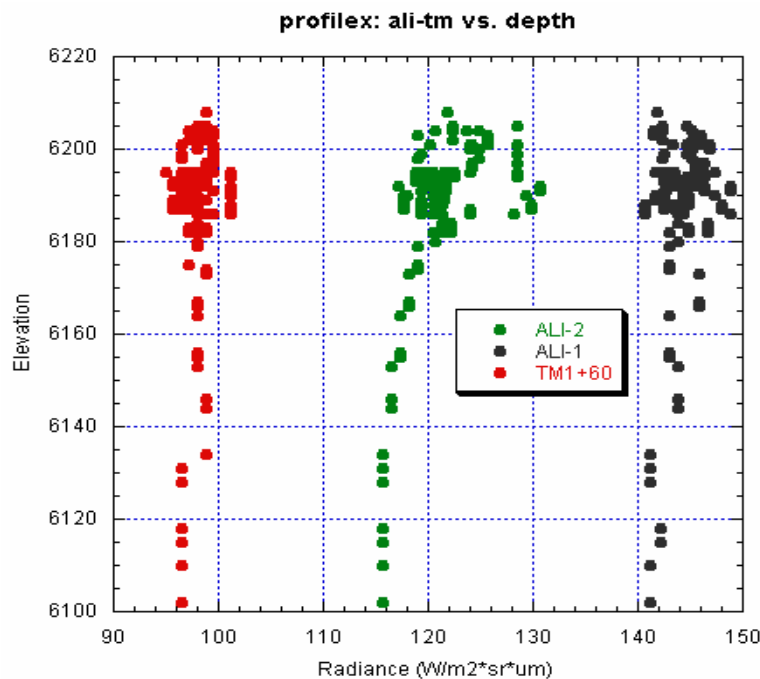


Figure 8. Depth vs. radiance plots for a profile from the shore of Lake Tahoe. The two similar 0.45-0.52 micron bands for ALI and ETM+ are plotted.

ALI data suggested penetration to a depth of 50 feet, and ETM+ Band 1 data showed no penetration, probably due to the very low signal-to-noise. A final plot shows the penetration of the ALI far blue band (Figure 9)

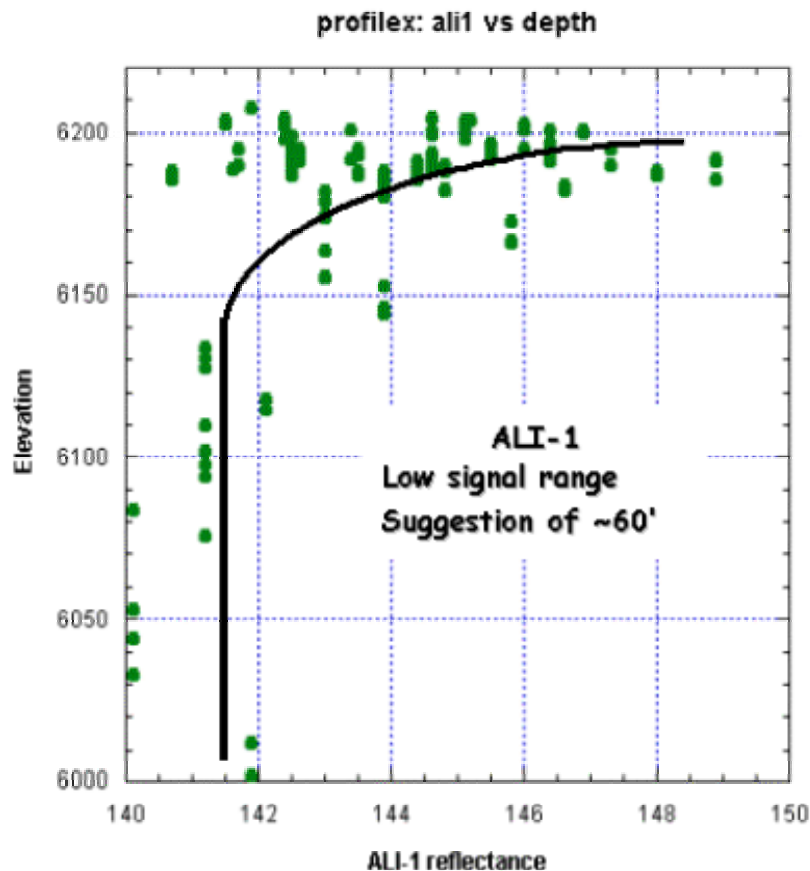


Figure 9. Depth vs. radiance for ALI far blue band.

The curve of depth vs. radiance became asymptotic at an elevation of about 6140 feet above sea level. This is at a depth of 60 feet.

Conclusion:

The analysis and comparison of ETM+ and ALI for depth penetration confirmed the initial hypothesis that ALI, with its higher signal-to-noise and additional far blue band, achieved greater depth penetration for bands equivalent to ETM+. Further, the far blue band achieved greater penetration than the traditional blue band.

Vegetation Mapping in the Venice Lagoon

In the Venice Lagoon, maps of submerged aquatic vegetation have been used to plan selective harvesting of benthic macro-algae and all activities relating to sea phanerogam plantations. Mapping techniques currently used have been based on in situ observations and aerial photo-interpretations. Results obtained with multispectral data have been limited to the detection of entire submerged vegetation cover.

In this study investigators compared the capability of ALI and ETM+ data to map submerged vegetation and separate different types of vegetation. Sea truth data was obtained from boat surveys at the time of the satellite overpasses.

ETM+ data proved to be of limited use in mapping vegetation. Image spectra derived from the data (Figure 10) showed very little distinction between macro-algae and phanerogam spectral signatures. Only discrimination of vegetation cover could be achieved.

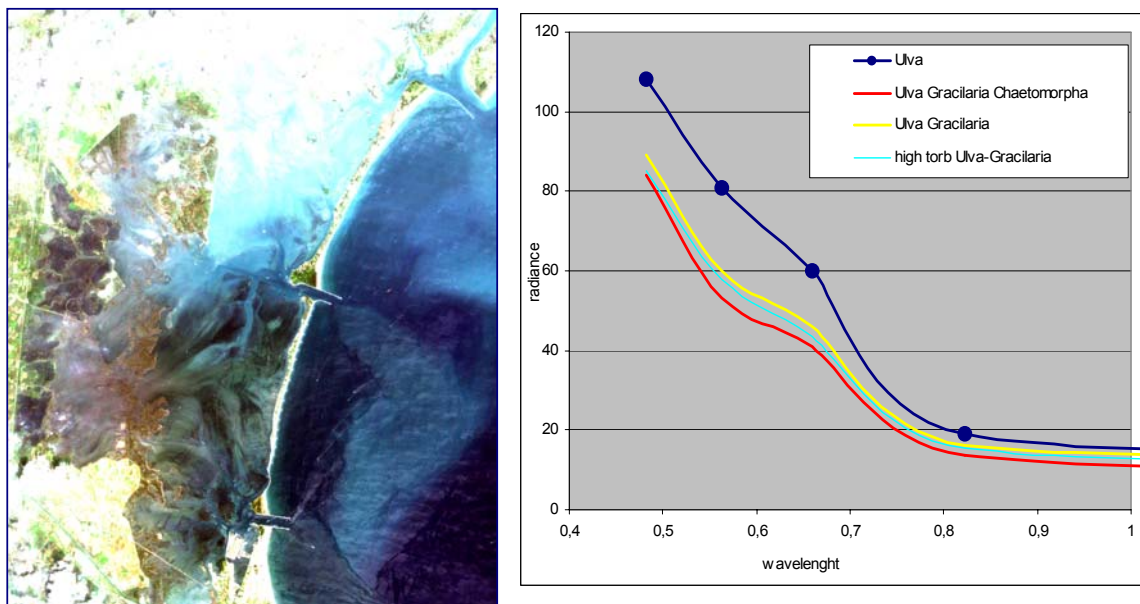


Figure 10. (Left) False color ETM+ composite image of Southern Basin in Venice Lagoon. (Right) ETM+ image spectra of macro-algae and phanerogam. Very little discrimination between species types is seen.

Information for the same areas were extracted from ALI data, and spectral signatures were plotted (Figure 11). The higher signal-to-noise of ALI as compared to ETM+ and the presence of a far blue band produced signatures that were distinct and well separated.

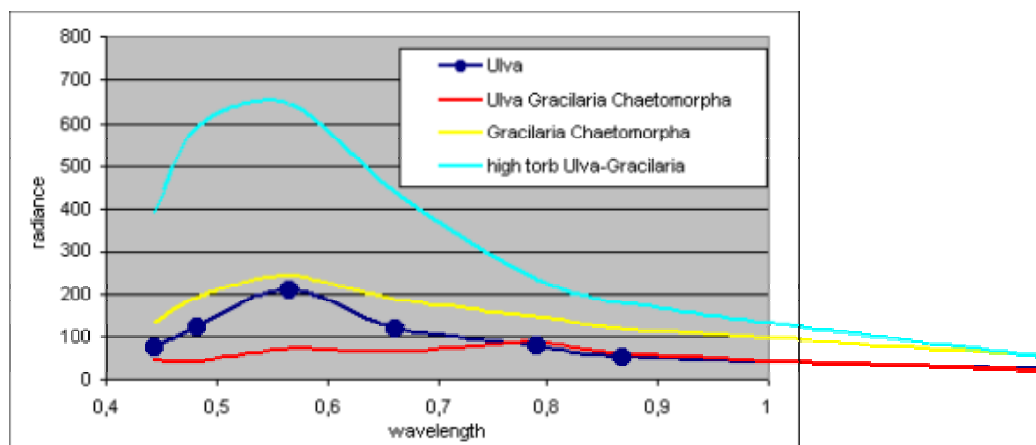


Figure 11. Spectral signatures derived from ALI data for lagoon vegetation types.

Sub-pixel mapping of vegetation types using ALI data was performed using the sub-pixel processing approach. The submerged vegetation species mixtures generated, for each pixel, a composite spectral signature. The analysis assumed that every pixel contained a fraction of the material of interest, and the remainder contained the background materials. The analysis detected the material of interest by subtracting fractions of candidate background spectra. The output was presented in the form of fraction planes (maps) for each material of interest. Analysis for benthic macro-algae and sea phanerogams is shown in Figure 12. The analysis used ALI bands 1-5 for spectral classification. Band 9 was used to mask out the land portion of the image.

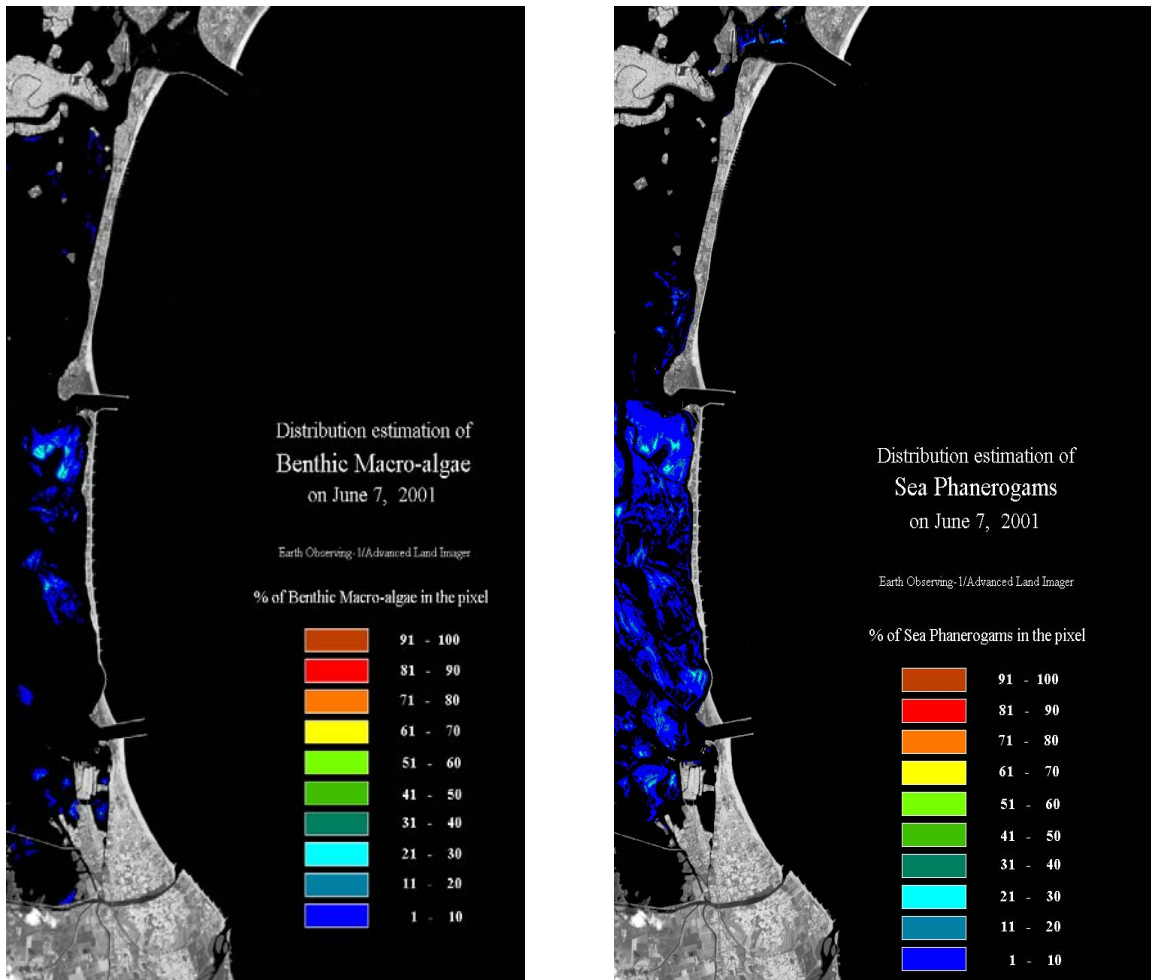


Figure 12. (Left) Sub-pixel processing classification of ALI data for benthic macro-algae. (Right) Sub-pixel processing classification of ALI data for sea phanerogams.

The sub-pixel processing approach also permitted mixture maps to be produced. For the two types of vegetation, a three-part classification was created: (1) dominantly sea phanerogams, (2) dominantly benthic macro-algae, and (3) a mixture of the two types. This was compared with sea-truth maps, and produced quite satisfactory results (Figure 13).

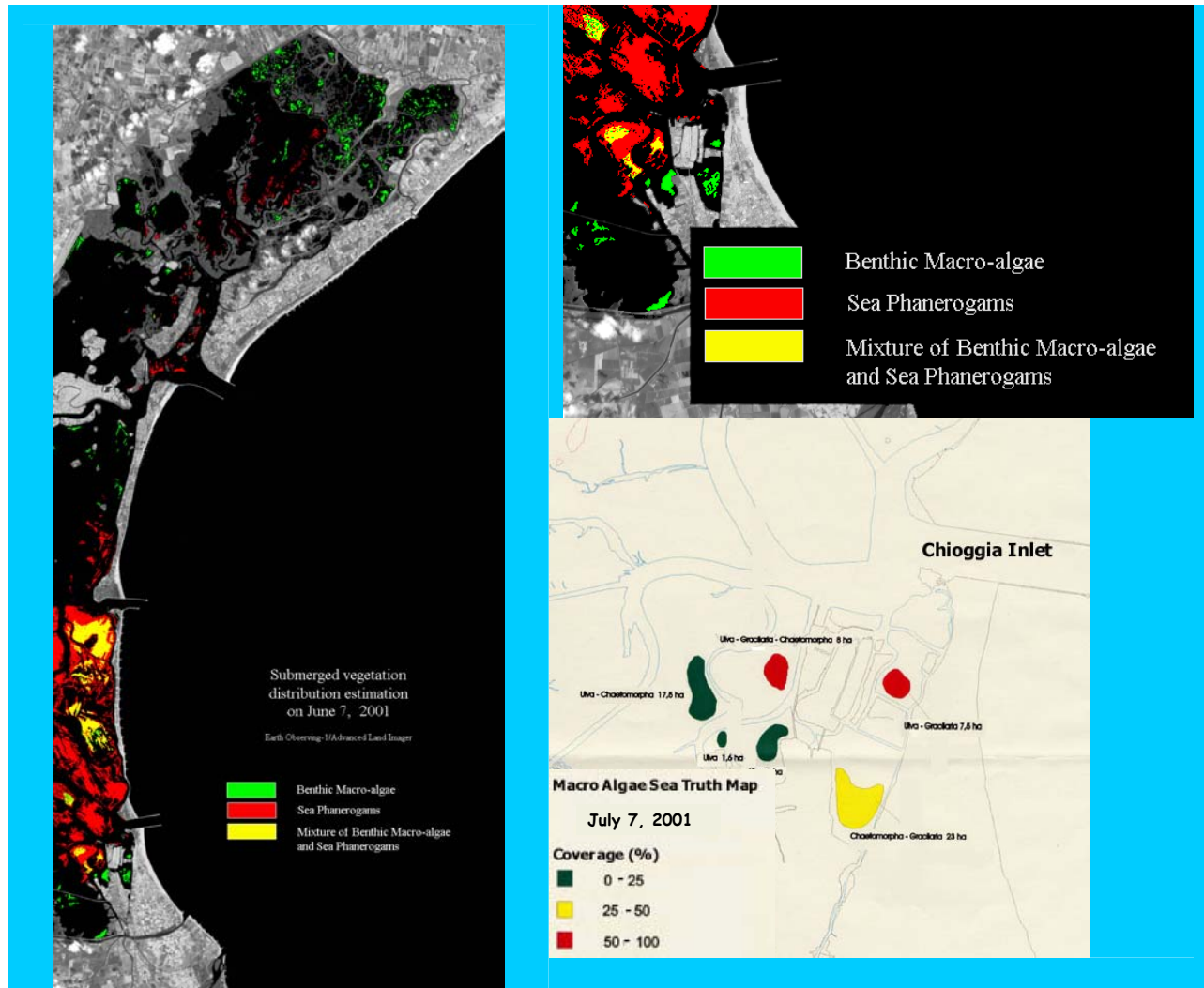


Figure 13. Sub-pixel processing mixture classification of benthic macro-algae and sea phanerogam in Venice Lagoon using ALI data.

Conclusion:

The comparison of ALI and ETM+ data for vegetation mapping in Venice Lagoon indicates that the improved signal-to-noise and additional blue band of ALI compared to ETM+ allow significantly better recognition and mapping of vegetation types.